

Bakerian Lecture. "Recent Advances in Seismology"

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BAKERIAN LECTURE.—“*Recent Advances in Seismology.*”

By JOHN MILNE, F.R.S.

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[PLATE 4.]

All who are interested in the progress of science recognise that at the present time Seismology receives an attention vastly different from that accorded to it only a few years ago. The old Seismology consisted of but little more than scattered accounts of great convulsions which altered the appearance of vast tracts of country and which were frequently accompanied by appalling destruction. For the most part these accounts were little better than the narratives which, in early times, exciting the imagination of primitive communities, gave rise to myths which have left their mark in literature, art, and religion.

Not until the interval between the years 1840 and 1860 by the strenuous labours of many workers, amongst whom Perry and Mallet were conspicuous, was a general knowledge of the distribution of earthquakes in space and time reached. Mallet, in his classical work on the Neapolitan earthquake of 1859, drawn up under the auspices of the Royal Society, showed that from the ruins of a town many facts of scientific importance could be gathered. This work, together with that of a few other seismologists, gave the first indications that earthquake phenomena lent themselves to systematic investigation. But little further progress was made until 1880, when as a side issue of Japan's material development along western lines, Seismology began to grow with great rapidity into its present form and became a distinct branch of observational science.

In that year the Seismological Society of Japan was founded. The 20 volumes which it has since published furnish accounts of original research in regard to most matters connected with seismological enquiry.

The first work accomplished by the pioneers of the new science was to devise instruments which would not simply indicate that the ground had been more or less violently shaken, but which gave measurements in the form of amplitudes and periods of all the phases of ordinary earthquakes. Seismometers of types which have found acceptance throughout the world took the place of seismoscopes. Facts now replaced mere opinions. In what had been supposed to be a succession of violent back-and-forward movements it was eventually discovered that no two of these had necessarily been in the same azimuth, and that the range of these movements instead of being measurable in inches or parts of inches did not exceed 1 or 2 mm.

By the use of the new instruments it was demonstrated that the range and rapidity of movement recorded at a given station might be very different from the corresponding quantities recorded at another station only a few hundred feet distant. Experience throughout the earthquake-shaken countries of the world had long before shown that ruin was frequently very much greater in one portion of a city than in another, but the seismograph supplied actual measures of the difference in intensity of motion by which this had been brought about. Engineers and constructors were not long in recognising that earthquake destructivity could be expressed in mechanical units and, therefore, they were in a position to design structures to resist known forces.

At the Imperial University of Tokio a platform was constructed which by means of powerful machinery could be made to reproduce earthquake motion of varying intensity. On this table large models of masonry, wood and metal, designed to resist expected seismic accelerations, were tested. This table has been to the builders in Japan what a testing tank in a dockyard has been to constructors of large vessels. The ultimate result of these and other investigations has been to modify and extend the rules and formulæ of ordinary construction, and now in Japan, as opportunity presents itself, new types of structure are springing up. These have withstood violent shakings which have materially damaged ordinary types in the neighbourhood. While much has thus been done to reduce the loss of life and property, the Japanese Government, stimulated by the results of this experience, has been encouraged to extend its support to seismological investigations in general.

In 1886 the Chair of Seismology was established at the Imperial University, and since 1892 there has been in existence a Seismological Investigation Committee, which has already issued 70 quarto volumes. At the Central Meteorological Observatory in Tokio records are received from nearly 1500 observing centres. From these records we learn that in Japan between 1000 and 2000 different shocks occur annually. For each of these an approximate origin and the extent of the area of disturbance can be determined.

The first earthquake catalogue which contained facts of this description was prepared partly by assistance given by the Royal Society. It showed that Japan might be divided into at least 15 distinct seismic districts. Thus seismologists were provided with data which led to investigations that had previously been impossible. From this compilation it was also at once seen that seismic activity, and, by inference, geotectonic changes, were different in different districts and that districts marked by the greatest seismic frequency are those which afford evidence of recent secular movements of upheaval or depression. If Japan be taken as a whole, the greater number of earthquake-origins are to be found on or at the base of its steep eastern suboceanic

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frontier, and only to a minor extent in the synclinal troughs of deep valleys. The greatest frequency for shocks originating beneath the ocean, Dr. Ōmori tells us, is in summer, whilst for those originating on land it is in winter. Whether this suggested seasonal distribution will be sustained by more extensive observation has yet to be determined.

In a district that has suffered from an unusually large disturbance the number of after-shocks appear to be proportional to the intensity of the initial impulse. The frequency of the movements is probably connected with the settlement of disjointed material, and its relation to time may be represented either as a formula or as a curve, from which we can roughly estimate (1) the time which will elapse before the district will reach a stable state, and (2) the approximate number of shocks which will occur during the process of settling.

From deductions based upon extensive observations we know that roughly speaking in the world some 30,000 shocks might be recorded annually. The corresponding number of megaseismic efforts is about 60. Either of these numbers may be used as an index of the present seismic vitality of our planet. Were it possible to extend this knowledge forwards or backwards through several ages we might estimate the time when hypogenic activities would fail to compensate for those the origin of which is external to our planet. The surface of our earth as it now exists has a life the length of which may yet be measurable.

The most remarkable development in modern seismology, however, is not the seismic survey of a city or even of a country, but of the whole world. This branch of enquiry is now in active progress. Since the time of the great earthquake of Lisbon in 1755 it has been known that disturbances of the magnitude of that event, although not directly recognisable as earthquakes in regions distant from the origin, have nevertheless given evidence of commotion by causing the water in lakes and ponds to oscillate. By observing and timing the movements of the bubbles of sensitive levels, astronomers have recorded unfelt pulsatory movements of the ground which they showed to be the result of seismic disturbances in far distant countries. In Japan these unfelt movements have been automatically recorded since 1884.* They were recognised to have originated at a great distance, but the centres from which they sprang were not determined. Some years later, while seeking for a gravitational influence of the moon, the late Dr. E. von Rebeur-Paschwitz found on his records abnormal movements, several of which he traced to definite but very distant seismic centres. Before this, indeed, it had been predicted that a large earthquake occurring in any one part of the world

* 'Seis. Soc. Trans.,' vol. 10, p. 6.

would produce movements which, with proper instruments, would be recorded in any other part,* but it was not until after von Rebeur's announcement that serious attention was directed to what has proved to be a line of research open to workers in all countries. Many instruments have been designed to record these unfelt breathings of our earth, but there is still much uncertainty in the interpretation of all their records.

At the present time the British Association enjoys the co-operation of 40 stations which are fairly evenly distributed over the world, and are each supplied with similar recorders. In Japan, Italy, Austria, Germany, Russia, the United States, and in other countries teleseismic movements are also observed, but the types of instruments employed are not identical. In the present experimental stage of the new investigations this diversity may be advantageous. From the records obtained from these different stations our knowledge of the earth is being increased principally in two directions. We are learning more about sudden changes that take place in the superficial covering of the globe, while new light is being thrown upon the physical constitution of its interior.

Earthquakes of the first magnitude, which disturb continental areas and frequently extend over the whole world, are in many instances if not in all, accompanied by bodily displacements of large masses of material within the terrestrial crust. When the origin of disturbance has lain under a land surface, rough estimates have been made of the magnitude of these mass-displacements, the estimates being based upon such observed facts as the measurable length and down throw of a fault or a series of faults, the extent of compression in valleys, the alterations in relative heights, or in the lengths of lines in trigonometrical surveys. Other estimates of these quantities may be founded on the measured amounts of upheaval or of subsidence of coast-lines. Evidence bearing upon the magnitude of sudden suboceanic changes are furnished by the cable-engineer, who supplies many illustrations wherein deep-sea cables lying in parallel lines are shown to have been simultaneously broken, and where the depths previously ascertained by soundings over considerable areas are found to have been largely increased. Earthquakes which are accompanied by sea waves able to agitate an ocean like the Pacific for 24 hours, suggest that beneath the ocean there has been some fairly sudden alteration in the contour of the sea-floor.

Observations also show that large earth-waves are from time to time propagated over the whole surface of the globe. These far-reaching commotions lead to the inference that their originating impulse must have been delivered over a large region. Harboe has shown that within a meizo-

* See "Earthquakes," p. 226, 'International Scientific Series,' 1883.

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seismic area blows of varying intensity have been struck in quick succession at points long distances apart. A district appears to have given way not simply along the line of one large fault, but along many minor faults. Oldham estimated that the Assam earthquake of 1897 had been accompanied by the bodily displacement of 10,000 square miles of country along a thrust plane. If we interpret the time observations made in connection with this disturbance in the light of the suggestion made by Harboe, then this relief of seismic strain originated over an area of 500,000 square miles.

Although a large block of the earth's crust may thus be fractured, our knowledge of the depth to which the effects of fracturing descend is largely one of inference. From the observations hitherto published, which are now in progress at Prizbram, it would seem that a seismogram obtained at a depth of 1150 metres differs but little from one obtained on the surface. This is contrary to observations on small earthquakes which, although they may alarm the inhabitants of a town and shatter chimneys, may pass unnoticed in shallow mines.

The fact that the large earth-waves have what is practically a constant areal velocity of approximately 3 kiloms. per second, whether the path be across continents, over ocean floors, or over districts which vary greatly in their geological structure, suggests the idea that the crust of the earth is moved as a whole, and that under the influence of its own elasticity and gravity it behaves in a manner similar to a sheet of ice upon an ocean swell. An alternative view is to assume that the wave motion is due to energy retained within the crust itself, the heterogeneity of which is superficial. Whichever be the case, we may picture a crust yielding irregularly, and possibly through its total thickness, until it gives up its energy to a medium which transmits undulatory movements with uniform velocity.

Many hypotheses have been adduced which suggest thicknesses for the superficial covering of our globe. To these as an outcome of recent seismological research we may add one more. Preceding the large waves of a teleseismic disturbance we find preliminary tremors. These are apparently propagated through the body of the globe with an average speed along paths which are assumed to be chords at about 10 kiloms. per second. This high and nearly constant rate of transmission, however, only obtains for paths which represent arcs greater than 30°. For chords which lie within a depth of 30 miles the recorded speeds do not exceed those which we should expect for waves of compression in rocky material. This, therefore, is a maximum depth at which we should look for materials having similar physical properties to those we see on the earth's surface. Beneath this limit the materials of the outer part of this planet appear

rapidly to merge into a fairly homogeneous nucleus with a high rigidity. Following closely on the heels of the preliminary tremors, but in advance of the large undulations, a second phase of motion appears, the chordal velocity of which up to distances of 120° is approximately 6 kiloms. per second. These are tentatively regarded as the outcrop of distortional waves. When these are better understood it may be expected that they also will play their part in shedding fresh light upon the physics of the earth.

I will now turn to a consideration of the regions in which these sudden accelerations of geological change are in operation. They may be grouped as follows :—

Regions which lie on the western suboceanic frontier of the American and the eastern frontier of the Asiatic continents, and regions which lie on a band passing from the West Indies through the Mediterranean to the Himalayas.

In addition to these there are two minor regions, one following the eastern suboceanic frontier of the African continent, which I have called the Malagassy region, and an Antarctic region which lies to the south-west of New Zealand.

The following table gives the number of large earthquakes or mass-displacements which have occurred in the subdivisions of these regions since 1899.

	1899.	1900.	1901.	1902.	1903.	1904.	Total.
Regions of the Pacific Ocean {							
1. East Indian Archipelago	11	17	13	14	11	9	75
2. The coast of Japan	19	5	5	9	7	14	59
3. Alaskan coast.....	14	11	1	1	3	0	30
4. Central America	6	4	4	8	6	0	28
5. West of South America	9	0	2	3	1	0	16
Western Atlantic and Eurasian regions {							
6. Antillian region.....	6	7	3	6	3	0	25
7. Azores	13	6	3	0	2	1	25
8. Alpine, Balkan, Caucasian, Himalayan region	4	2	8	22	22	4	62
9. Malagassy district.....	9	4	4	1	3	0	21
10. Antarctic district	Between March, 1902, and November, 1903, 75 large and small disturbances were recorded.						
Totals	91	56	43	64	58	29	341

Many of the disturbances included in this table are known to have been followed by hundreds and even thousands of after-shocks. The most active district is at present that of the East Indies, which might well be considered as an eastern prolongation of the Himalayan region. The scene of this activity, it may be noticed, is at the junction of two lines of rock folding, which meet almost at right angles. Whether the Antillian and Central American regions should be separated is open to question. If we unite

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their registers as belonging to two comparatively near and parallel earth ridges, the movements of one influencing those of the other, we have a region of hypogenic activity approximating to that of the Japan seas.

Generally it would appear that these regions of instability are to be found along the margins of continents or tablelands which rise suddenly to considerable heights above oceanic or other plains.

At the present time we may, therefore, say that megaseismic disturbances do not occur anywhere, but only in districts with similar contours. Are we dealing with primitive troughs and ridges which are simply altering their dimensions under the continued influence of secular contraction, or do these reliefs of seismic strain represent isostatic adjustments which denudation and sedimentation demand?

These and other activities may be looked to as primal causes leading up to displays of pronounced seismic activity. Their frequency, however, may be dominated by influences which at certain seasons or times cause an increase or decrease in seismic strain.

In the wide variations in position and rapidity of flow of ocean currents and in measured oscillations of sea level which appear to be seasonal in their recurrence, we see influences which may give rise to seismic frequency in districts that possess a high degree of seismic sensibility. Other causes affecting large areas and also possibly the frequency of small or after-shocks in different seismic districts have by Knott and others been sought for in the loads due to the accumulation of snow, and in the seasonal fluctuations in the direction of barometric gradients. It does not seem likely, however, that stresses due to such influences have any marked effect upon the frequency of those reliefs of seismic strain which shake the world.

The data which we possess bearing upon this question are as yet far too meagre to admit of satisfactory analysis. It is, nevertheless, interesting to note the direction in which they point. In the six years ending in 1904 we find that off the West Coast of North America 51 large earthquakes originated during the winter months (October to May) and 35 during the summer months. Off the East Coast of Asia, north of the equator, the numbers for these seasons were 49 and 43. These numbers added together show that for the North Pacific, as a whole, 100 disturbances took place in winter and 78 in summer, while in the Central Asian or Himalayan region the corresponding numbers are 25 and 27. Beneath an ocean, therefore, some indication has been obtained of seasonal seismic frequency, while on a continental surface no such frequency has yet been indicated.

If we take a chart showing the varying position of our earth's North Pole

in relation to its mean position, we see that the secular movement of the pole is by no means always uniform. Although it may at times follow a path about its mean position which is approximately circular, at other times there are comparatively sharp changes in direction of motion which may even become retrograde. If now on a chart of this description we mark the time-positions of very large earthquakes, we find that they cluster round the sharper bends of the pole path. (See Plate 4.)

In a period of nearly 13 years (1892 to 1904) I find records for at least 750 world-shaking earthquakes, which may be referred to three periods continuous with each other, and each two-tenths of a year or 73 days' duration. The first period occurs when the pole movement followed an approximately straight line or curve of large radius, the second equal period when it was undergoing deflection or following a path of short radius, and the third when the movement was similar to that of the first period. The numbers of earthquakes in each of these periods taken in the order named were 211, 307, and 232, that is to say, during the period when the change in direction of motion has been comparatively rapid, the relief of seismic strain has not only been marked, but it has been localised along the junctions of land blocks and land plains where we should expect to find that the effect of general disturbances was at a maximum. It can hardly be assumed that the frequency under consideration is directly connected with change in direction of pole movement; but it seems not unlikely that both effects may arise from the same redistribution of surface material by ocean currents and meteorological causes generally.

As we have now considered some of the more important phenomena which accompany the birth of a world-disturbing earthquake, we may next turn to its life and death. In and near an epifocal area it occasionally happens that before the vibrations which follow the first great heaving of the ground have ceased, a second violent movement may occur. In Japan this repetition has earned for itself the name of the Yuri Kaishi or "return shaking." Possibly it may be simply a second yielding within the disturbed tract, but its resemblance to its precursor suggests that it may perhaps be the resultant of some pronounced reflection. Following the initial impulse and its echo come groups of waves, separated by short intervals of time, during which movement is hardly perceptible. Although these groups as a whole grow more and more feeble, they rise and fall in their intensity. From time to time there may be repetitions of groups which have a striking similarity to each other. (See Plate 4, fig. 3.)

A world-shaking earthquake wherever its motion is pronounced gives rise to movements which may extend over three or four hours. They come to

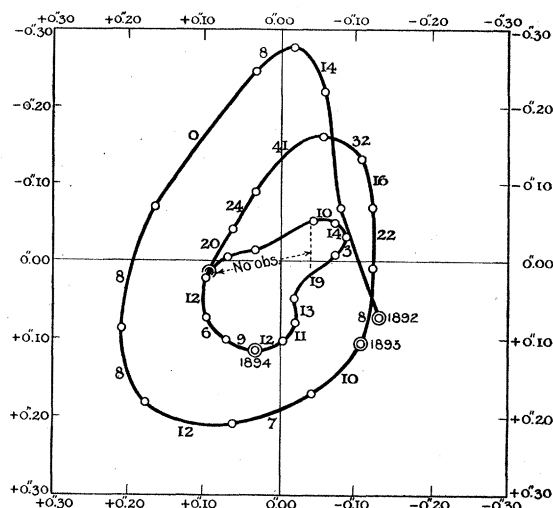


FIG. 1 shows, after Th. Albrecht, the path of the North Pole from 1892 to 1894 inclusive. Each year is divided into tenths or periods of 36.5 days. Numerals indicate the number of large earthquakes which occurred in each of these divisions, commencing with the third tenth of 1892.

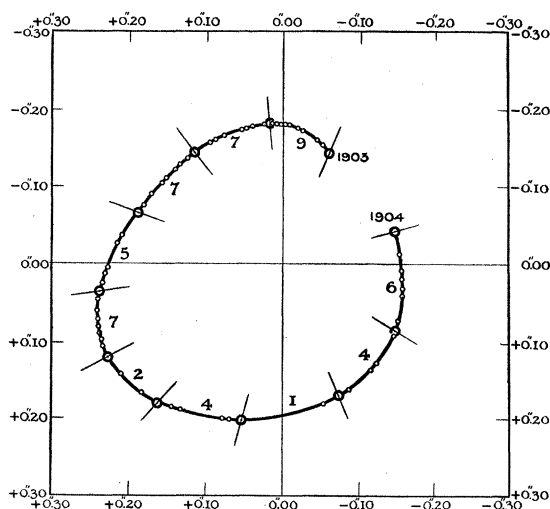


FIG. 2.—This is similar to Fig. 1, but refers to the year 1903, during which period the pole displacement was more uniform than that indicated in Fig. 1.

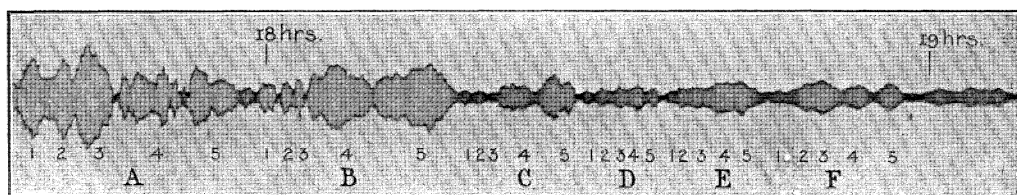


FIG. 3.—Recurrences of Wave Groups A to F in the terminal vibrations of the Colombian Earthquake of January 31, as recorded at Shide, Isle of Wight. Scale 87 mm. = 1 hour.

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a close as a series of pulsations each lasting a few minutes and separated from each other by approximately equal intervals of rest. The expiring efforts of an earthquake present something more akin to musical reverberation than to intermittent and irregular settlement of disjointed material.

If instead of studying the life-history of an earthquake as recorded at a given station, we compare the seismograms it has yielded at different distances from its origin, we learn something of the manner in which its energy has been radiated and dissipated. An earthquake which in the vicinity of its origin has a duration of 60 minutes may appear at its antipodes 90 or 100 minutes later as a feeble movement with a duration of only four or five minutes. From the time this movement has taken to travel the half circumference of the globe the inference may be drawn that the surviving phase of such an earthquake is that of the large waves. The compressional and distortional precursors, together with the rhythmical succession of followers, are no longer visible on seismograms. The importance of this knowledge to those who are engaged in the analysis of earthquake-registers is apparent.

Another curious feature connected with the history of these antipodean survivors is that they may pass the quadrantal region unrecorded. What takes place may be compared to the passage of a wave down a rapidly widening estuary and to its passage up a second but similar estuary. Half-way on its journey the wave may not be perceptible, but as it converges along the latter part of its path it may again in a modified form yield indication of its existence. Other interesting investigations which have recently been made with regard to a certain class of large earthquakes refer to the peculiar form of the areas which they have disturbed. These may be described as narrow ellipses or bands which pass from an origin farthest round the world in one particular direction. The suggestion is that for this class of disturbance the primary impulse was delivered in the direction of the line of furthest propagation.

An accompaniment to earthquake radiation is seen in records of secondary earthquakes which are small and local in their character, and take place at the times when teleseismic movement has reached the district in which they are felt. A large earthquake in one district may therefore not only be regarded as the parent of many after-shocks within its own district, but it may also be related to responses in very distant places. No such relationship has yet been discovered between the larger readjustments in the earth's crust.

From the table given on p. 370 it is seen that since 1899 in the Alaskan

region seismic frequency has distinctly decreased, while in the Himalayan region it has increased. The paucity of available data, however, renders it premature to make deductions respecting possible alternation in seismic frequency in localities such as we have mentioned. But if, instead of confining our attention to a relationship between earthquakes, we consider the question of the relief of volcanic strain, many illustrations may be adduced which indicate a close connection between such activities. For example, all the known volcanic eruptions which have occurred in the Antilles from the first which took place in 1692, have been heralded or closely accompanied by large earthquakes in that region, but more frequently by like disturbances in neighbouring rock-folds, particularly that of the Cordilleras. This was notably the case in 1902. On April 19 of that year an unusually large earthquake devastated cities in Guatemala. Small local shocks were felt in the West Indies, and on April 25 it was noticed that steam was escaping from the crater of the Montagne Pelée, in Martinique. These activities continued to increase until May 8, when they terminated with terrific explosions, submarine disturbances, and the devastation of great portions of the Islands of Martinique and St. Vincent.

The last illustration of hypogene relationship between these regions occurred on January 31 of the present year. On that date a heavy earthquake originated off the mouth of the Esmeralda River, in Colombia. Sea-waves inundated the coast, islands sank, and a volcano erupted. The newspapers of February 2 announced that cables between Jamaica and Puerto Rico had been interrupted, and on later dates it was reported that severe shocks had been felt among the West Indian Islands, that six or seven submarine cables had been broken, and that Mte. Pelée and La Soufrière, in St. Vincent, were again active.

In concluding this short discourse I wish to draw attention to a class of phenomena from which the working seismologist cannot escape. At certain times horizontal pendulums may be fitfully moving continuously for hours or even days. Similar movements have often been noticed with balances and with other instruments. They are frequently referred to as micro-seismic disturbances. Inasmuch as they vary with varying meteorological conditions, and may be different in neighbouring rooms, I am inclined to think that it would be more accurate to describe these unwelcome visitors, with which not only seismologists, but also astronomers and others have to contend, as air tremors. When, however, these irregular movements are replaced by movements which have definite periods very different from those of the recording instrument itself, and are at the same time regular in amplitude, it seems possible that they may be connected with actual

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pulsatory motion of the surface of the ground. In addition to tremors and pulsations, the records on the films from seismographs show that nearly at all times a slow change of level is taking place. For years a pier may be undergoing a tilt in one direction. Besides this general movement the instruments reveal the existence of waves that indicate a difference in the direction of movement in different seasons. Superimposed upon these again we find records of changes of level which may be associated with variations in the difference in loads on two sides of an observing station. When a horizontal pendulum swings towards the area of greatest atmospheric pressure it apparently indicates a change directly or indirectly connected with barometric loading. The quantity of water in wells and that flowing in drains and from springs has been observed to vary with fluctuations in atmospheric pressure. Where this takes place, sub-surface operations are revealed which may be sufficient to give rise to changes in surface level. When a squad of 76 men marched to within 16 or 20 feet of the Oxford University Observatory it was found that a horizontal pendulum inside the building measured a deflection in the direction of the advancing load. The observation that a surface dips in the direction of a load it carries may however be unexpectedly modified. The concrete floor of a cellar on the strand at Ryde has with the rise of the tide in the Solent been observed to tilt towards the land, whereas the anticipated direction of change in level was in the contrary direction. In this instance the rising water in all probability masked its own gravitational effect by backing up sub-surface drainage, with the result that the foreshore was floated or lifted upwards. Very marked changes of level take place at certain stations during wet weather. In the Isle of Wight, at Shide, which is situated on the side of a valley cut through an anticline of chalk, when heavy rain occurs, levels and horizontal pendulums indicate a tilting towards the bed of the valley. An instrument on the opposite side of the valley behaves in a corresponding manner. In other words, if these observed movements can be regarded as extending to the bed of the valley, it may be said that with rain the steepness of each of its sides is increased. During fine weather the direction of movement is reversed. A more regular movement is, however, found in a tilting known as the diurnal wave. With the same assumption as to the extent of corresponding motion we find, but only during fine weather, that the direction of movement of the sides of the same valley during the night corresponds to that observed during wet weather. During the day it is the same as that which takes place during fine weather. For convenience we may regard the valley as opening and closing. Similar observations have been made on the two sides of a valley which has been cut through alluvium in Tokio.

This diurnal movement is only marked on days which are bright and sunny. On dull, cloudy, or wet days it is small or not recordable. In a chamber 13 feet beneath the surface, excavated in soft ground where changes in temperature are very small, I have found the diurnal movement to be quite as marked as at neighbouring installations on the surface, where temperature changes were comparatively large. I have not observed it in excavations made in rock at depths of 50 and 100 feet. At Bidston, however, in the New Red Sandstone, at the depth of 19 feet, changes of $0''\cdot1$ and $0''\cdot2$ are from time to time recorded. On flat, open country the variation is small at all times. An influence which probably plays an important part in the production of these movements may be sought for in the differential loading and unloading of neighbouring areas by solar influences. During wet weather, in virtue of sub-surface percolation and lateral drainage generally, the sides and bottom of a valley where water-level is raised, carry a greater load than the bounding ridges. Under these conditions the bottom of a valley may sag and its sides close inwards. During fine weather, in virtue of evaporation and drainage, a movement in the opposite direction may be established. The fine-weather diurnal movement corresponding to the opening of a valley may find a partial explanation in the removal of load by evaporation, but more particularly by plant-transpiration. These activities are more pronounced during the day than at night, and they tend to reduce sub-surface percolation and drainage towards the bed of a valley. The comparatively small retrograde nocturnal movement may be partly attributed to an increase of valley load at night, at which time transpiration and evaporation are replaced by surface and sub-surface condensation. Transpiration and evaporation being at a minimum at night, it may be assumed that lateral percolation and surface drainage towards the bed of a valley are increased, and possibly as a consequence of this action, the volume of water in certain wells and that flowing in certain streams and drains has been found to be greater at night than during the day.

Another activity which may result in a nocturnal increase in the sub-surface flow of water is the expansion of the air in soil by the slowly descending heat of the previous day, this expansion forcing soil-water into passages of easiest escape.

The explanation offered for the phenomena under consideration may be found wanting ; but the facts remain, that round the face of the globe diurnal superficial distortions can be observed which vary in magnitude and direction, and that rainfall is accompanied by measurable changes in the slopes of certain valleys. These surely are facts that deserve recognition.

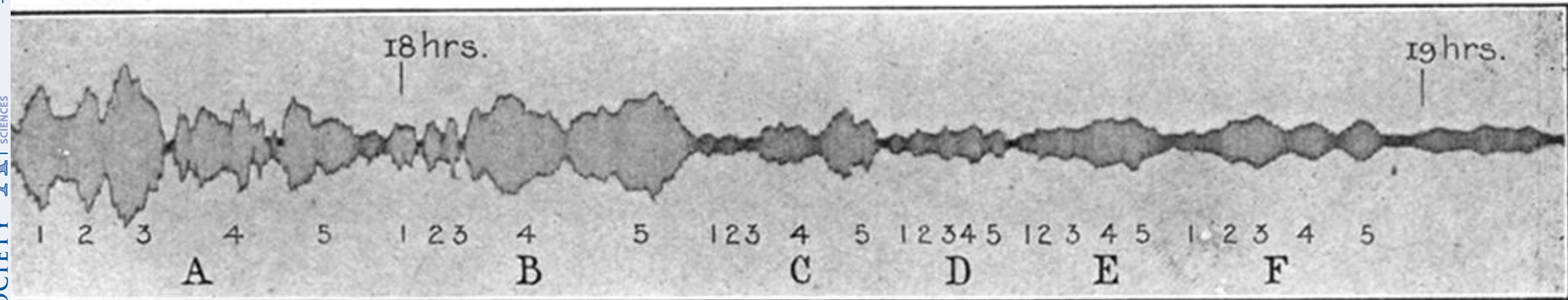


FIG. 3.—Recurrences of Wave Groups A to F in the terminal vibrations of the Colombian Earthquake of January 31, as recorded at Shide, Isle of Wight. Scale 87 mm. = 1 hour.